Strength and Deformation Characteristics on Stabilized Pavement Geomaterials

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ABSTRACT

The stabilization techniques in the pavement foundations have advantages in increasing the pavement performance and reducing pavement layer thicknesses. By mixing the geomaterials and stabilizer, the structurally sound layer can be added in the pavement system. Until now, these techniques have been applied in the field empirically and the design criteria for stabilization has not been established in Korea. The purposes of this paper are to evaluate the mechanistic properties of stabilizers used for geomaterials and determine the type and optimum amount of stabilizer for each technique. The unconfined compressive testing and repeated load resilient modulus test were conducted on the coarse grained soils mixed with various types of stabilizer to investigate the strength and deformation characteristics of stabilized geomaterials. It is found from these tests that the unconfined compressive strength of stabilized geomaterials is more than ten times higher than that of gradation modified geomaterials. The resilient modulus of stabilized geomaterials increases by 6~10 times compared to the original soils and tends to increase with increase of volumetric and deviatoric stress, and amount of stabilizer.

1. INTRODUCTION

Due to the rapid increase of highway construction in these days, the aggregates and soils as a pavement material are short supply and their cost tends to be increased in Korea. To overcome these problems, the various research efforts have focused on the development of the new materials to replace the existing geomaterials and improvement of the strength and durability of geomaterials. The stabilization techniques in the pavement foundations are capable of not only increasing the pavement performance but also reducing the pavement layer thickness. The stabilized layer with an optimum amount of stabilizer is economical and structurally stable. However, these techniques have been applied in the field empirically and the design criteria for stabilization have not been established in Korea.

This study is to evaluate the mechanistic properties of stabilizers used for geomaterials and determine the type and optimum amount of stabilizer for each technique.

2. MATERIALS AND TEST METHODS

Geomaterials

The subbase and subgrade materials that have been sampled in test road of Chungbu Inland Expressway and Doochon~Eoron construction site of Gyeonggi Province were used in this testing.

The specific gravity testing, sieve analysis and standard compaction testing were conducted to obtain the basic material properties shown in Table 1. Gradation curve and compaction test results are shown in Figures 1 and 2, respectively.

Table 1.Engineering Properties of Geomaterials used in the Study

Location		Test Road		Doochon~Eoron Site	
Layer		Subbase	Subgrade	Subbase	Subgrade
Sample Index		GW-1	SW	GW-2	SM
Grain Size Analysis	D10 (mm)	0.26	0.15	0.16	0.0075
	D30 (mm)	2.2	0.63	2.8	0.095
	D60 (mm)	13	2	14	0.78
	Cg	1.4	1.3	3.5	1.5
	Cu	50	13.3	87.5	104
	#200 Passing (%)	3.38	4.92	7.43	24.3
	#4 Passing (%)	43.09	93.82	38.48	85.30
Specific Gravity		2.717	2.653	2.703	2.689
Plasticity Index (%)		NP	NP	NP	6.8
Soil Classification		GW	SW	GW	SM
Compaction Test	OMC (%)	5.51	9.42	6.42	15.8
	d_{max} (kN/m^3)	21.58	18.86	23.20	17.74

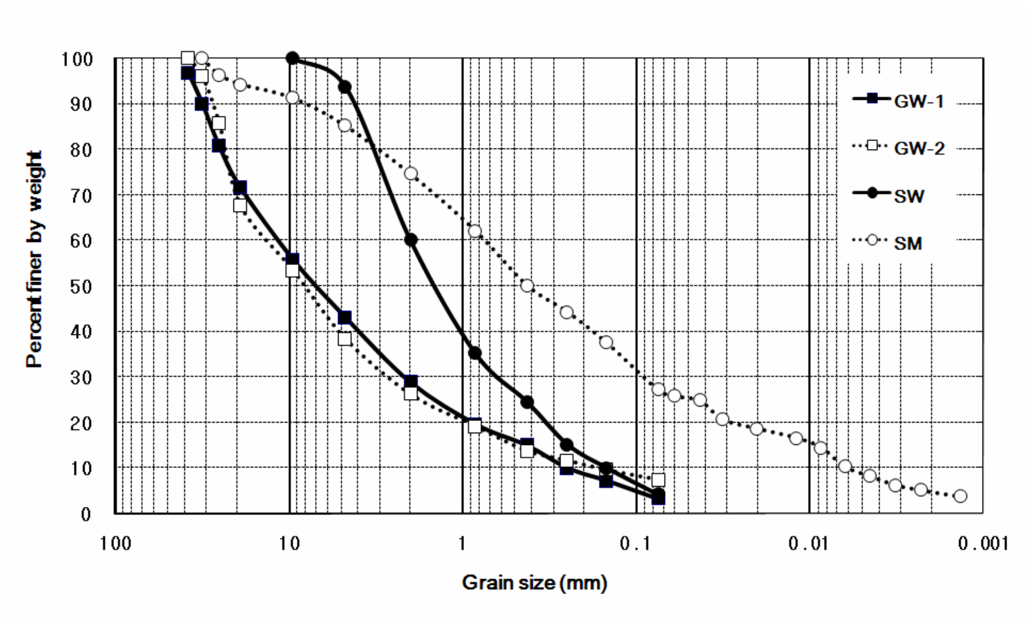
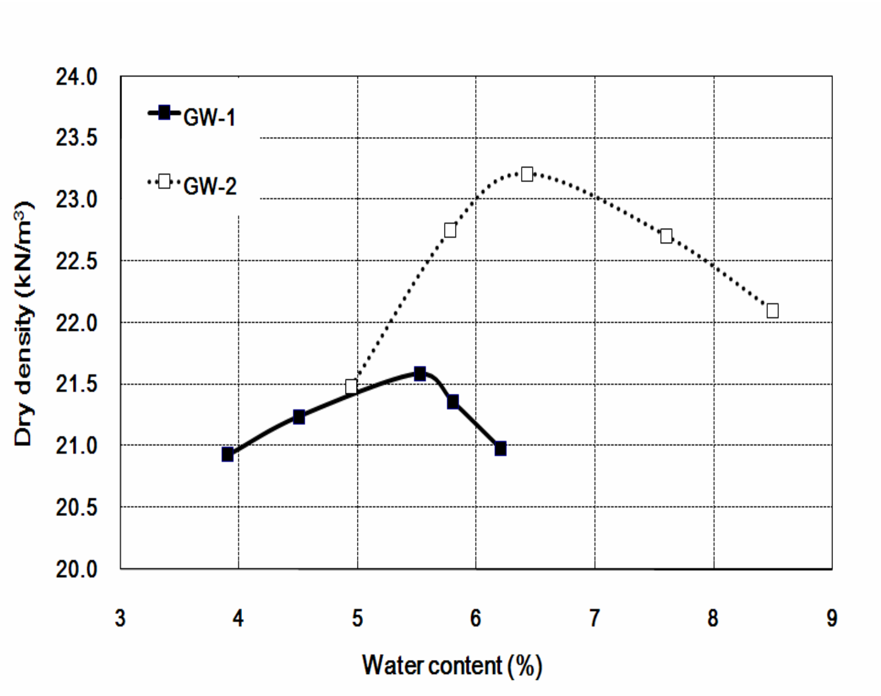
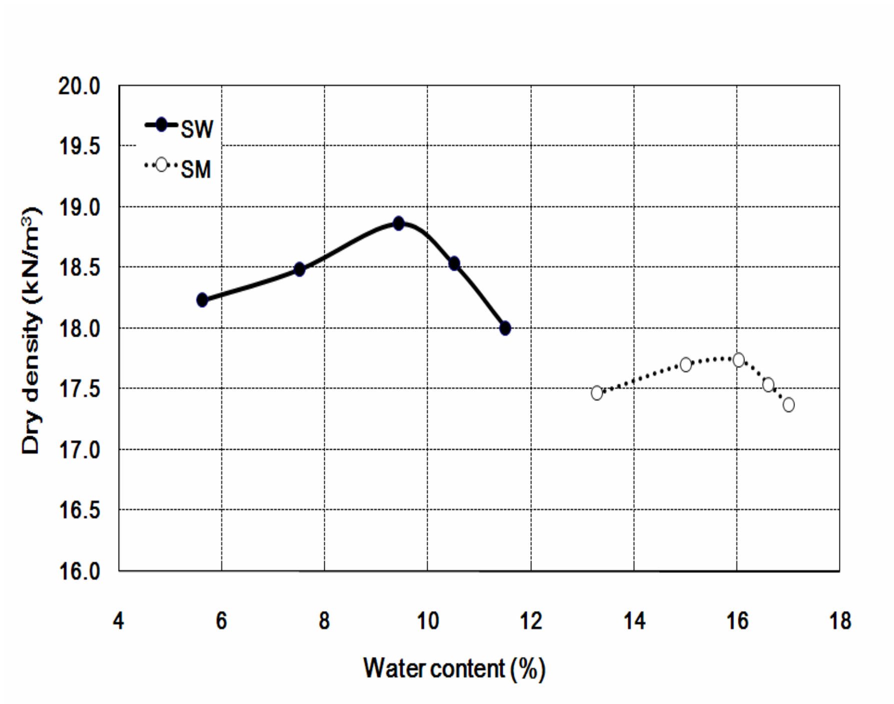


Figure 1.Gradation Curve



(a) Subbase



(b) Subgrade

Figure 2.Results of Compaction Test for Subbase and Subgrade Materials

Stabilizer

A total of three stabilizers (Portland cement, hydrated lime and quick lime) that have been most widely used in Korea were selected in this study (MOCT, 2000 and KHC, 2002). A different amount of fly ash was mixed with soil-stabilizer mixture to evaluate its effect on the mechanistic improvement of original geomaterials.

Sample Fabrication and Test Method

The specimens were prepared with different percentages of stabilizer by dry weight of soil. All the specimens with a 100mm in diameter and 150mm in height were compacted by using gyratory compactor at optimum moisture content. After compaction process, the specimens were cured for seven days at 25°C of temperature and 95% of relative humidity. Unconfined compressive testing was conducted on prepared samples at 1%/min of deformation rate. The resilient modulus of each specimen was determined according to AASHTO TP 46-94 (Standard Test Method for Determining the Resilient Modulus of Soils and Aggregate Materials).

3. Laboratory Tests and Results

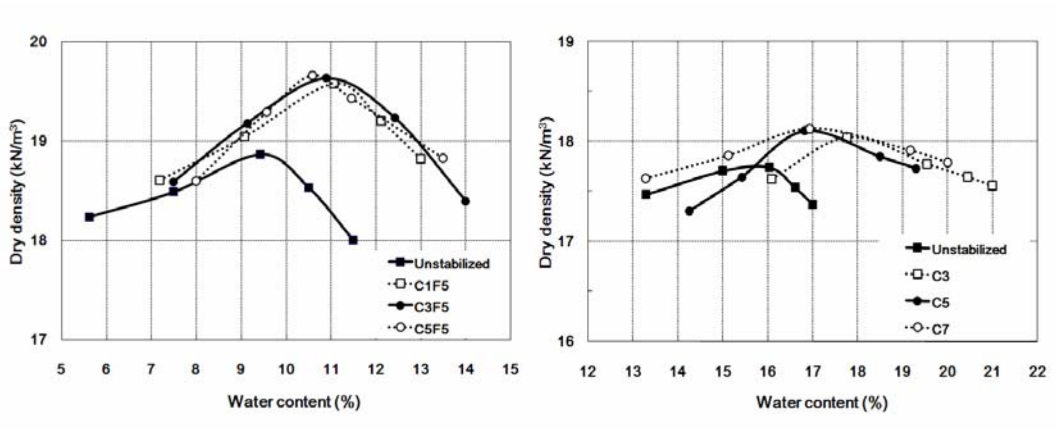
Geomaterials and Stabilizer Mixture Design

In general, the stabilized mixtures have been tested based on the maximum dry density (MDD) and the optimum moisture content (OMC) determined by the compaction tests. However, it is only applicable to determination of mechanistic properties of the specific stabilized materials and is not appropriate for evaluating the different types of stabilizer at same condition. Rather than conducting the compaction testing of soils with different amount of stabilizer, the results of compaction testing for original soils were used for mixture design (Hopkins, 1994). Table 2 summaries the laboratory test condition for each specimen.

Table 2. Laboratory Test Conditions for Various Mix Designs of Stabilized Mixture

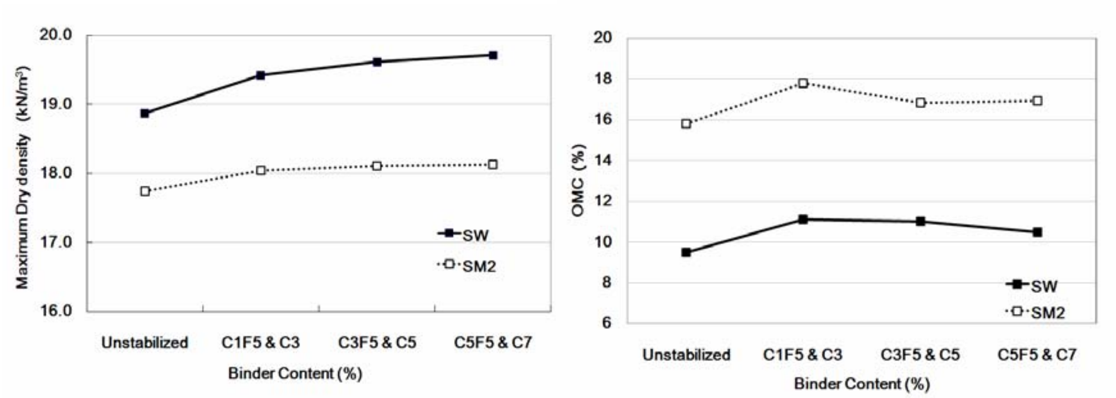
Soil	Mix Design	Sample Index	Stabilizer Type and Quantity	Moisture Content (%)	Dry Density (kN/m^3)	Test Method
SW	OMC*	C1F5	C(1%), F(5%)	9.42	18.83	UCS M_R
		C3F5	C(3%), F(5%)			
		C5F5	C(5%), F(5%)			
	OMC	C1F5	C(1%), F(5%)	11.10	19.42	
		C3F5	C(3%), F(5%)	11.00	19.61	
		C5F5	C(3%), F(5%)	10.48	19.71	
SM	OMC*	C3	C(3%)	15.80	17.74	UCS
		C5	C(5%)			
		C7	C(7%)			
	OMC	C3	C(3%)	17.80	18.04	
		C5	C(5%)	16.82	18.11	
		C7	C(7%)	16.94	18.13	

Figure 3 shows the compaction test results for different percentages of stabilizer. It is found from this figure that the MDD and OMC for stabilized mixture are higher than the original soil. The MDD slightly increases as the amount of stabilizer increases in the mixtures. Figure 4 shows change of MDD and OMC with increase of stabilizer content.



(a) Cement + Fly ash (b) Cement

Figure 3.Compaction test results for different percentages of stabilizer contents



(a) MDD (b) OMC

Figure 4.Change of MDD and OMC with increase of stabilizer content

Unconfined Compressive Strength for Different Type and Amount of Stabilizer

The type 1 Portland cement, hydrated lime, quick lime, and fly ash were selected as stabilizers to evaluate the effect of strength improvement on untreated soils. The unconfined compressive testing was conducted by changing from 5 to 20 percent of stabilizer content. Since there was no increase in compressive strength for GW-1 and SW soils with 20% of stabilizer, this content for SM soil were excluded from the testing. The GW-2 was also eliminated due to similar properties with GW-1.

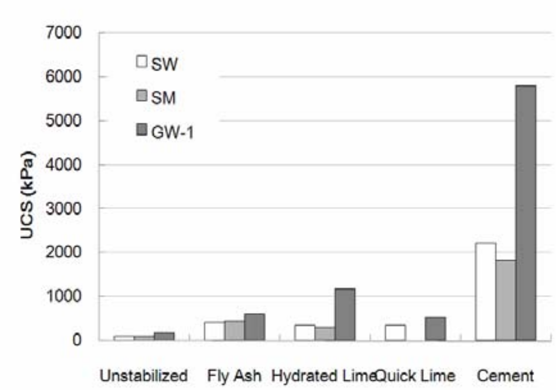
Table 3.Laboratory Testing Condition for Comparison of Different Stabilization Effect

Original Soil	Type of Stabilizer	Stabilizer Content (%)
SW GW-1	Fly Ash: F	5 10 20
	Hydrate Lime : H	
	Quick Lime : Q	
	Cement : C	5 10
SM	Fly Ash : F	5 10
	Hydrate Lime: H	
	Cement: C	

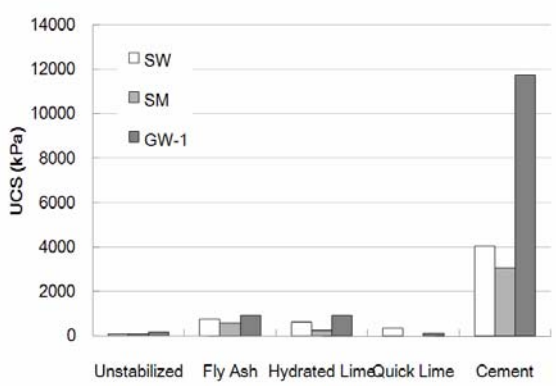
Figure 5 shows the results of unconfined compressive strength testing for various types and contents of stabilizer. Regardless of soil type, there is significant increase in compressive strength when using a cement stabilizer. Compared with SW and SM specimens, the GW-1 shows the highest strength gain. Although stabilized mixtures with fly ash, hydrated lime, and quick lime show a higher unconfined compressive strength than the untreated soil, their strength are lower than that of cement stabilized mixture.

Except for cement stabilizer, 20% for other stabilizers shows increase in strength comparing to the untreated soil, but significant decrease comparing to 5% and 10%. A mixture with quick lime was failed during the curing process. It is probably due to the strength reduction caused by the volume expansion by reaction process of CaO and water inside of soil.

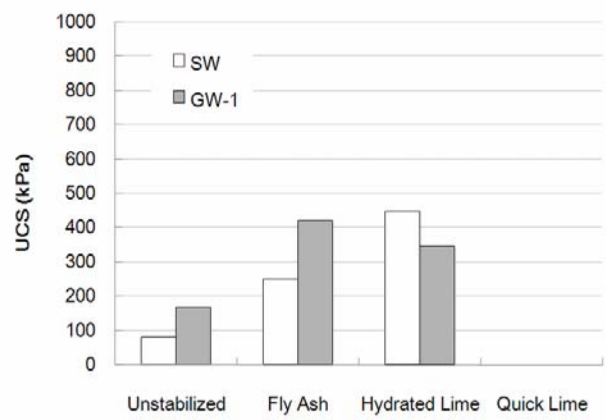
Based on this test, fly ash itself as a stabilizer may not be enough to increase the compressive strength of mixture. Since tests in this study were conducted with 7-day curing, strength may be increased more after curing more in terms of long term strength improvement. However, for 7-day curing, stabilization with another additive to fly ash will be more effective on strength.



(a) Stabilizer Content = 5%



(b) Stabilizer Content = 10%



(c) Stabilizer Content = 20%

Figure 5.Unconfined Compressive Strength for Different Type and Amount of Stabilizer

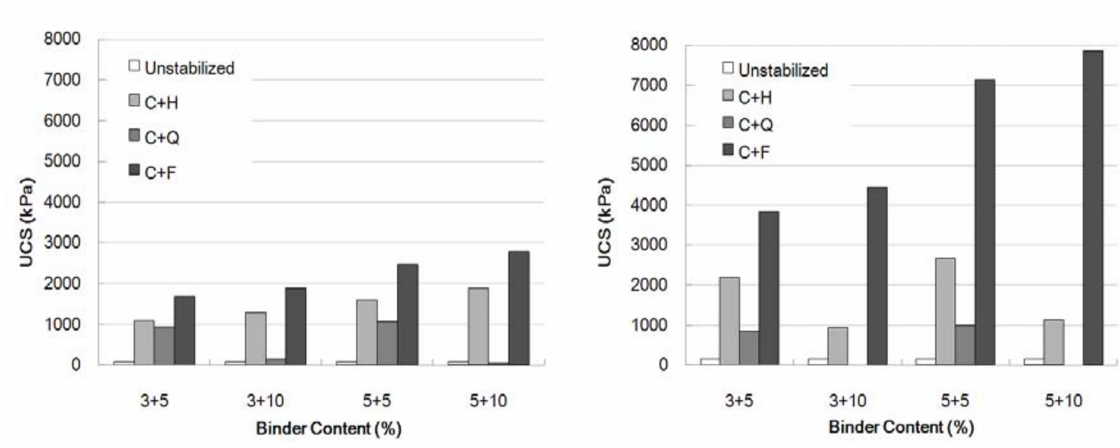
UCS for Mixed Stabilizers

For 7-day curing, using the compound with different stabilizers can increase the compressive strength. Therefore, SW and GW-1 soils were used to evaluate the strength gain by the stabilizer compound following the test plan shown in Table 4.

Table 4.Test Conditions for Mixed Stabilizers

Soil	Type of Stabilizer	Stabilizer Content (%)
SW GW-1	Cement + Hydrated Lime : C+H	3+5 3+10 5+5 5+10
	Cement + Fly Ash :C+F	
	Cement + Quick Lime : C+Q	
	Fly Ash + Hydrated Lime : F+H	
	Fly Ash + Quick Lime : F+Q	

According to the unconfined compressive strength test results for stabilizer compounds shown in Figure 6, the mixture with cement and fly ash has the highest strength improvement. Even though hydrated lime had strength gain as much as fly ash had, cement and fly ash are more effective as a stabilizer compound.



(a) SW (b) GW-1

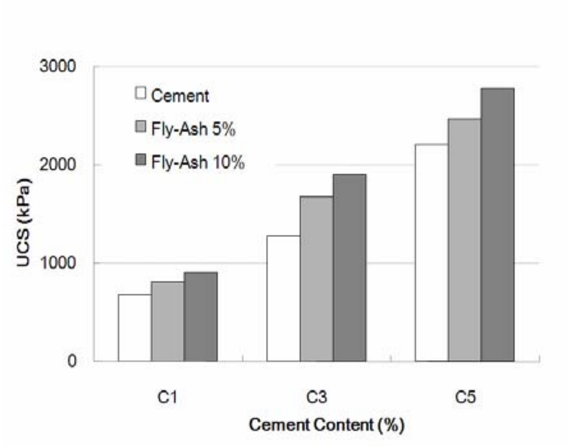
Figure 6.Unconfined Compressive Strength for Different Type and Content of Stabilizers

The stabilizer compound with cement and fly ash achieved higher strength. Therefore, another case for different amount of cement and was tested with different types of soils (Table 5).

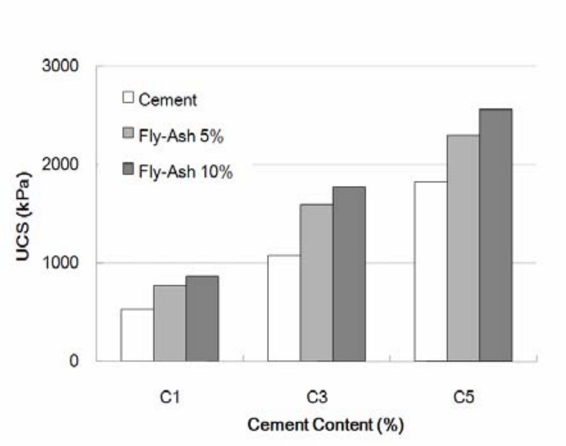
Table 5.Laboratory Testing Condition

Soil	Index	Type and Content of Stabilizer
SW SM GW-1 GW-2	C1	C(1%)
	C3	C(3%)
	C5	C(5%)
	C1F5	C(1%), F(5%)
	C1F10	C(1%), F(10%)
	C3F5	C(3%), F(5%)
	C3F10	C(3%), F(10%)
	C5F5	C(5%), F(5%)
	C5F10	C(5%), F(10%)

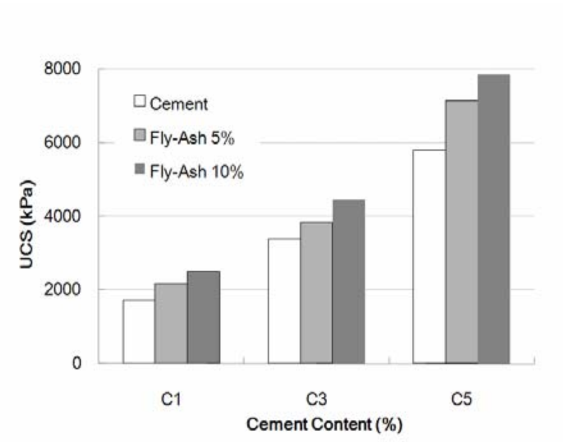
As shown in Figure 7, the stabilizer compound with cement and fly ash showed higher compressive strength than the cement stabilizer for all types of soils. Since 70 % of the subgrade is SW and SM, the compound of cement and fly ash will perform better in Korea.



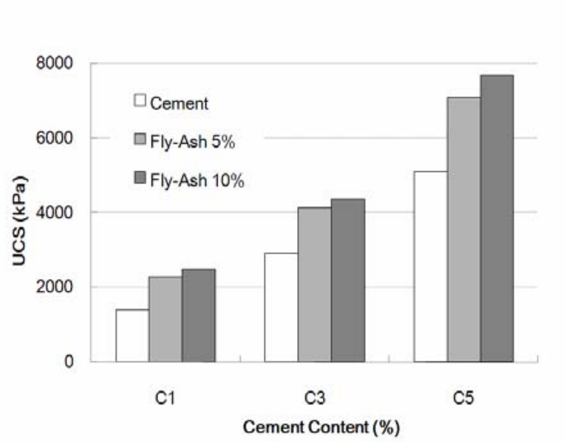
(a) SW



(b) SM



(c) GW-1



(d) GW-2

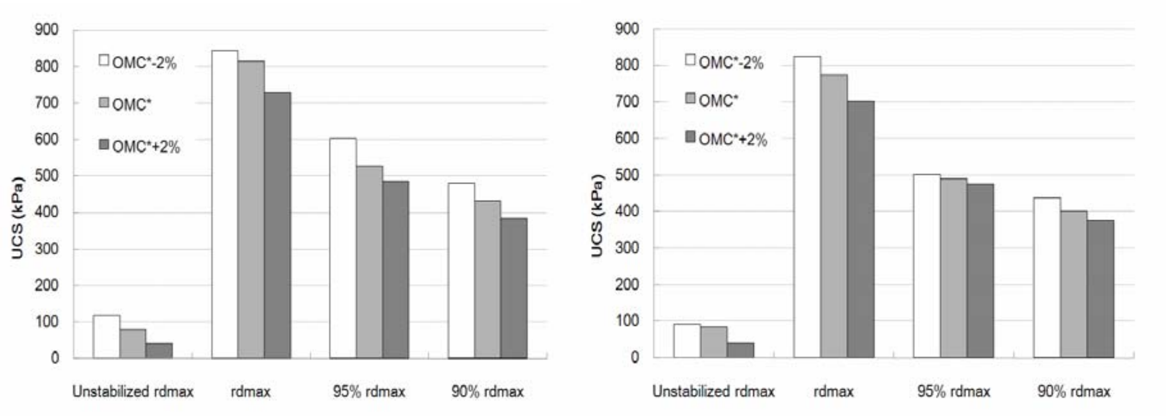
Figure 7.Unconfined Compressive Strength of Cement and Fly Ash Stabilized Materials

According to Dutron (1961)'s study, various types of soils, amounts of stabilizers, dry densities, and moisture contents were evaluated in terms of geomaterials stabilization of the pavement substructure. The tests were carried out to see the geomaterials properties on compressive strength by types of soils, dry density, and moisture content. The specimens were fabricated with SW and SM for 90, 95, and 100% of the maximum dry density. The moisture contents were ranged from -2 to +2% to investigate the effect of dry and wet conditions.

Table 6.Laboratory Testing Conditions with Characteristics of Geomaterials

Soil	Compaction Effort (%)	Dry Density (kN/m^3)	Moisture Content (%)	Type and Content of Stabilizer
SW	90	16.97	7.42 9.42 11.42	C(1%), F(5%)
	95	17.92		
	100	18.86		
SM	90	15.97	13.8 15.8 17.8	
	95	16.85		
	100	17.74		

Figure 8 shows the unconfined compressive strength test results with change of characteristics of geomaterials. It is observed from this test that the compressive strength increases as a dry density increases. Similar to research results done by Dutron (1961), the compressive strength of a specimen in dry condition has higher than that in the wet condition. The stabilized geomaterials increases strength by about four times compared to the untreated (original) soil even with 90% dry density and wet condition which had lowest compressive strength. Therefore, the amount of stabilizer is the most important key to control the compressive strength, even though others (i.e., moisture content, dry density) also play a role.



(a) SW (b) SM

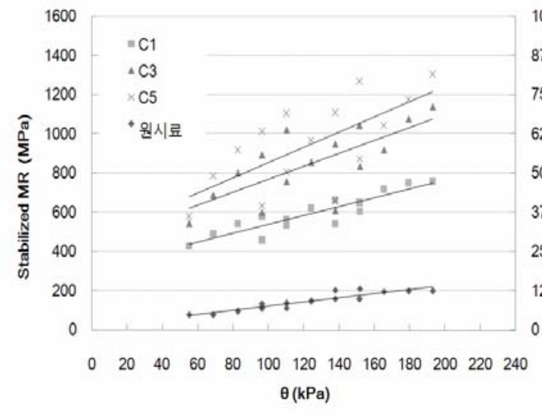
Figure 8.Unconfined Compressive Strength with Characteristics of Geomaterials

The Characteristics of Resilient Modulus by Using Stabilizer Compound

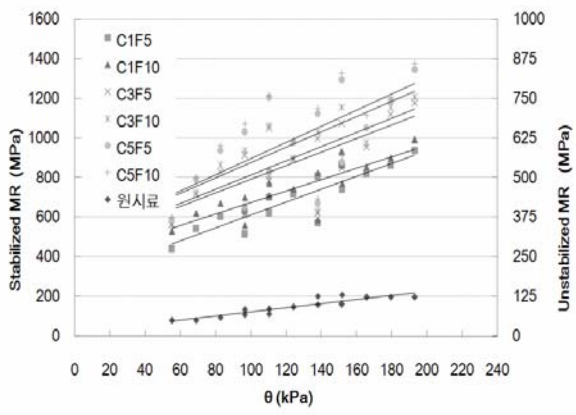
Based on the unconfined compressive strength test results which were significantly affected by the amounts of stabilizer, the repeated load resilient modulus test was conducted on the specimens for different amounts of stabilizer. Since the stabilizer compound with cement and fly ash showed higher strength value, it was compared to the cement stabilization.

Table 7 Testing Procedure of AASHTO TP 46-94

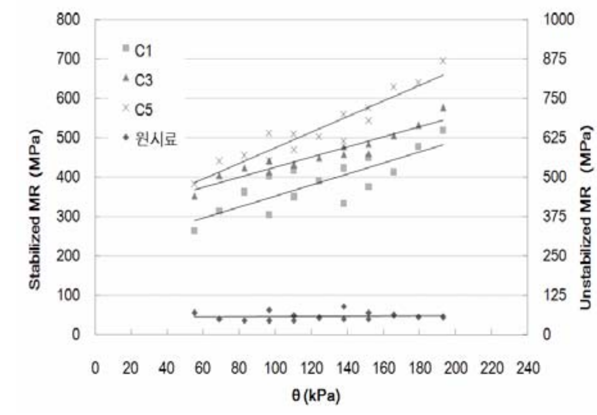
	Subgrade		Subbase		No. of Load Repetitions
	Confining Pressure (kPa)	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Deviatoric Stress (kPa)	
conditioning	41.4	27.6	103	103	500-1000
1	41.4	13.8	20.7	20.7	100
2		27.6		41.4	100
3		41.4		62.1	100
4		55.2	34.5	34.5	100
5		68.9		69	100
6	27.6	13.8		103.5	100
7		27.6	69	69	100
8		41.4		138	100
9		55.2		207	100
10		68.9	103.5	69	100
11	13.8	13.8		103.5	100
12		27.6		207	100
13		41.4	138	103.5	100
14		55.2		138	100
15		68.9		276	100



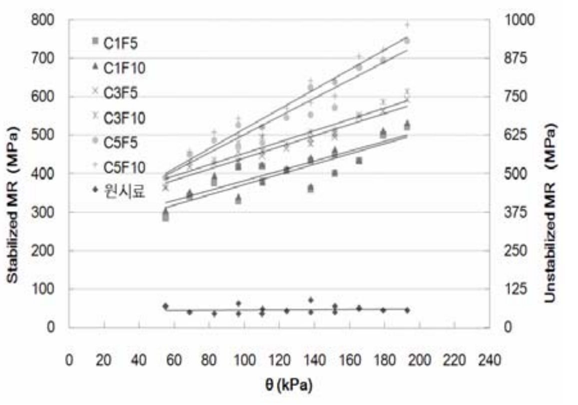
(a) SW: Cement



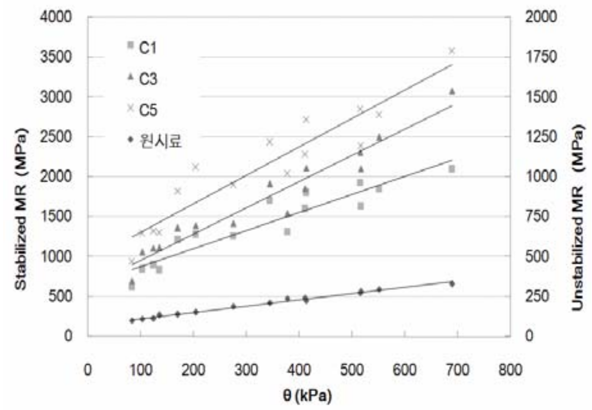
(b) SW : Cement + Fly Ash



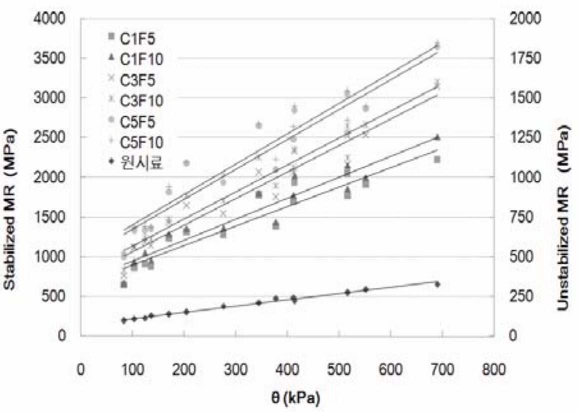
(c) SM: Cement



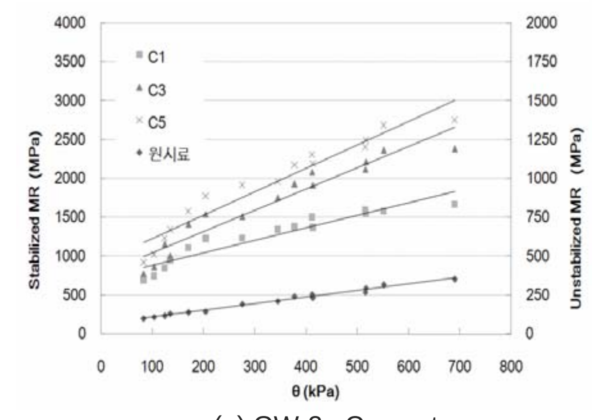
(d) SM : Cement + Fly Ash



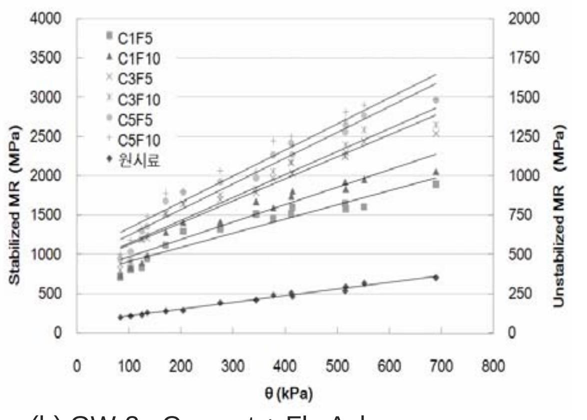
(e) GW-1 : Cement



(f) GW-1 : Cement + Fly Ash



(g) GW-2 : Cement



(h) GW-2 : Cement + Fly Ash

Figure 9.Results of Resilient Modulus Test

Figure 9 shows the resilient modulus test results for different soil type, stabilizer type, and amount of stabilizer. The resilient modulus for a specimen after stabilization was about six times higher than that of an original soil specimen. In addition, the resilient modulus increased as volumetric stress and amount of stabilizer increased regardless of types and amounts of soils. When comparing between cement stabilization and cement and fly ash compound stabilization, this confirms the result from the unconfined compressive strength test, that the specimen with cement and fly ash compound has higher resilient modulus than the specimen with the cement only as a stabilizer. As the unconfined compressive strength test result, the resilient modulus also increases by adding more fly ash.

4. Conclusions

This paper presents the results of the confining compressive strength testing and repeated load resilient modulus testing to evaluate various stabilization methods for coarse-grained geomaterials widely used in the pavement substructure in Korea.

1. The effects of soils and mix design on stabilization were evaluated by the unconfined compressive strength and repeated load resilient modulus. Since the characteristics of strength and deformation for different mix design are similar, it will be simple and effective to use the mix design method based on the compaction test results of the untreated (or original) soils.

2. The compressive strength for stabilized geomaterials showed about ten times higher than that for gradation modified geomaterials. In addition, the gradation for stabilized geomaterials plays a significant role in compressive strength. To have better effects on stabilization, it needs to have gradation more than certain limitation.

3. According to the unconfined compressive strength testing for stabilized materials using various stabilizers, the cement is the most affecting stabilizer in improving the compressive strength. However, for the stabilizer compound, the combination of cement and fly ash has more strength gain for the condition of 7-day curing.

4. The amount of stabilizer is the most important key to control the compressive strength.

5. The resilient modulus for a specimen after stabilization is approximately six times higher than that of an original soil specimen. In addition, the resilient modulus increases as volumetric and deviatoric stresses and amount of stabilizer increases. The specimen with cement and fly ash compound has higher resilient modulus than the specimen with the cement only as a stabilizer.

Acknowledgement

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